National Power & Energy Conference (PECon) 2004 Proceedings, Kuala Lumpur, Malaysia



# A Comparative Study of PI and Fuzzy Logic Automatic Voltage Regulator of A Micro-Alternator System

Saiful Jamaan, Md Shah Majid, Mohd Wazir Mustaffa, Hasimah Abdul Rahman

***Abstract*--A micro-computer based PI and fuzzy logic automatic voltage regulator is applied to a micro-alternator system. This paper describes the design and implementation of PI and Fuzzy Logic automatic voltage regulator of a micro-alternator. A comparative study of PI and Fuzzy Logic AVR is analyzed and results show that the Fuzzy Logic improves the system damping subject to disturbances. Borland Delphi is used to develop the software algorithm for the controller.**

***Keywords*--Automatic voltage regulator, Fuzzy Logic Control, Proportional Integral, Micro-alternator system**

## I INTRODUCTION

A synchronous generator or alternator is equipped with an automatic voltage regulator (AVR), which is responsible for keeping the output voltage constant under normal operating conditions at various load levels. The control algorithm is generally implemented using analog components. Recently fuzzy logic based controllers have been gaining increasingly acceptance. A fuzzy logic control (FLC) uses fuzzy logic as a design methodology that can be applied in developing linear and non-linear system for embedded control. FLC techniques have been found to be a good replacement for conventional control techniques that require highly complicated mathematical models. Fuzzy logic simplicity enables the control designers to realize a control in less development time, at lower development cost and with better performance. Researchers are using fuzzy control in various power system applications [1].

This paper presents a micro computer based PI and fuzzy logic automatic voltage regulator applied to micro-alternator system. A comparative study of PI and Fuzzy Logic AVR is analyzed. Result show that the Fuzzy logic improved the system damping subject to disturbances. A Borland Delphi is used develop the software algorithm for the controller [2].

## II MICRO-ALTERNATOR SYSTEM IN GENERAL

Generally, a micro-alternator system is a unit of synchronous generator that acts as an electric power system. The block diagram of the micro-alternator is as shown in Fig. 1.

The micro-alternator system consists of a synchronous generator, a DC motor and load. It is a unit of synchronous machine because it operates at constant speed; at synchronous speed and constant frequency under steady state condition.

This project is sponsored by Ministry of Science, Technology and Innovation, IRPA code 72226

The authors are with Power Engineering Department, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM, Skudar, Johor Darul Takzim, Malaysia.



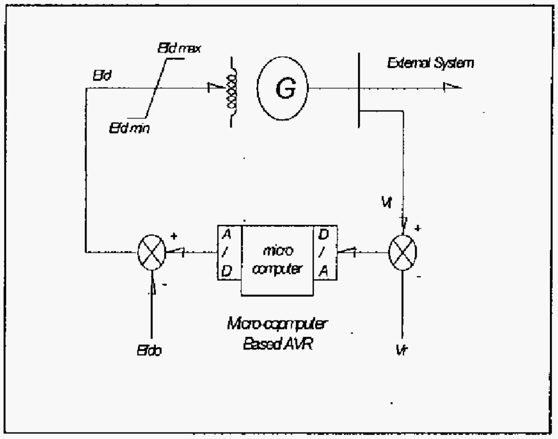



Fig. 1. Block diagram of a micro-alternator

### A. Automatic Voltage Regulator.

AVR is used to maintain the terminal voltage as far as possible constant. By comparing the terminal voltage ($V_t$) and the reference voltage ($V_{ref}$) and then feeding back the error of terminal voltage ($\Delta V_t$) to control the excitation, the situation can be achieved. Response variations can in some circumtances cause the AVR to introduce negative damping degrading system stability [1].

When the terminal voltage drops, the increasing of field excitation will cause the increase in generated voltage, E. Therefore, the terminal voltage can be maintained at a constant value when the connected load or voltage of system changes. A simple AVR is given by transfer function as in equation (1):

$$G(s) = \frac{100(s+1)}{10.4s+1} \qquad (1)$$

## III FUZZY LOGIC CONTROL SYSTEM

The basic idea behind fuzzy logic control is to incorporate the expert experience of the human operator in the design of the controller in controlling a process whose input-output relationship is described by a collection of fuzzy control rules involving linguistic variables.

### A. Configuration of a Fuzzy Logic Control System

The main FLC processes are fuzzification, rules definition, inference and defuzzification. A typical structure of a fuzzy logic control system is shown in Fig. 2.

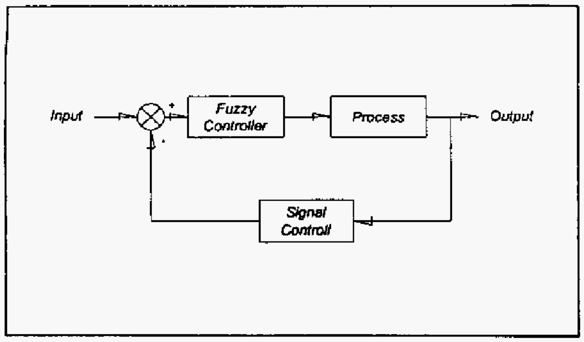



Fig. 2. A Typical Fuzzy Control System

Basically a fuzzy logic controller sits in a control system configuration similar to that of any typical controller (eg similar to such that of a PID controller). It is used to regulate the variable to be controlled such as voltage, speed, temperature, position, etc. by calculating the error in the system. [6]

*B. Components of the Fuzzy Logic Controller*

Fuzzy logic controller generally comprises four principal components: fuzzifier, knowledge base, inference engine and defuzzifier. Fig. 3 shows the structure of a fuzzy controller. If the output from the defuzzifier is not a control action for the process, then the system is a fuzzy logic decision system. The fuzzy controller itself is normally a two-input and single-output component. It is usually a MISO system. [7]

In Fuzzy logic control system there are 4 processes need to be considered, these processes are :

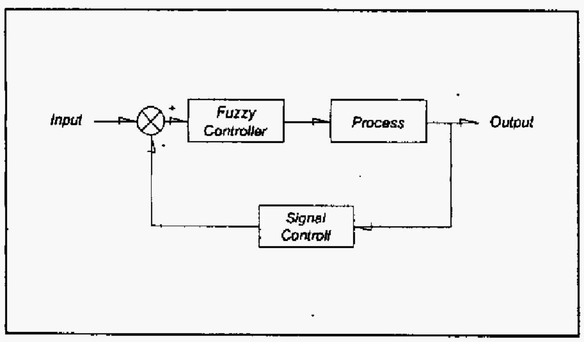



Fig. 3. The Structure of a Fuzzy Controller.

i). Fuzzification. Fuzzification mapping non-fuzzy input value to fuzzy input value. Generally, it is explained as Xz = fz (x) where x is input value, Xz is fuzzy variable and fz is fuzzy control. Fuzzification involved distribution function of fuzzy membership variable using triangle distribution is given in Fig. 4. Input value limit, which is converted to fuzzy value, is (-R, +R).

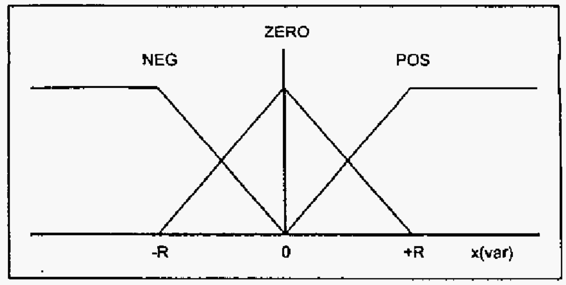



Fig. 4. Fuzzification function

ii). Basis of knowledge. In this fuzzy logic control typical learning of control plant is principal knowledge. It consists of Data Basis, a linguistic and manipulated data of control method definition. Rule Base is the explanation of dynamic characteristic input plant by linguistic base on expert experience. In examples:

a. If V constant and $\Delta V = 0$, then output constant

b. If V high and $\Delta V$ = positive, then output high

c. If V low and $\Delta V$ = positive, then output low

d. If V low and $\Delta V$ = negative, then output high

iii). Inference. Inference process is interpretation of rules in fuzzy operation method basis. Inference is simulating human decision base on logic method. This part will decide which control signal need to be generated base on fuzzy logic rule. 3 fuzzy sets rule is given below.

TABLE I
3 FUZZY SETS RULE

| Acceleration value $d\Delta V$ | | | |
|---|---|---|---|
| | N (neg) | Z (zero) | P (pos) |
| N (neg) | N | N | Z |
| Z (zero) | N | Z | P |
| P (pos) | Z | P | P |

The rule is generally explained based on 2 inputs and 1 output as follows:

Method 1 :

If $\Delta V$ = N and $d\Delta V$ = N Then u = N
If $\Delta V$ = N and $d\Delta V$ = Z Then u = N
If $\Delta V$ = N and $d\Delta V$ = P Then u = Z
If $\Delta V$ = Z and $d\Delta V$ = N Then u = N
If $\Delta V$ = Z and $d\Delta V$ = Z Then u = Z
If $\Delta V$ = Z and $d\Delta V$ = P Then u = P
If $\Delta V$ = P and $d\Delta V$ = N Then u = N
If $\Delta V$ = P and $d\Delta V$ = Z Then u = P
If $\Delta V$ = P and $d\Delta V$ = P Then u = P

iv). Defuzzification. Defuzzification is a fuzzy value mapping into non-fuzzy value. In this case changing control signal (u) into non-fuzzy values ($u_0$) because the signal object is non-fuzzy. A lot of method is used for fuzzification, i.e.: weighted average defuzzification.

$$U_0 = \frac{\sum_{j=1}^{n} \mu_j(\mu).u}{\sum_{j=1}^{n} \mu_j(u)}$$

where

$U_0$ : non-fuzzy value

$\mu_j(u)$ : membership of fuzzy value

$u_j$ : average fuzzy value

## IV. DEVELOPMENT OF MICRO-COMPUTE FLC AVR PROGRAM

Once the 'Fuzzy AVR' button is clicked by the user, a form called Fuzzy AVR will appear on the screen as shown in Fig. 5. The 'Fuzzy Parameter' tab sheet allows user to modify the controller parameters easily from the screen. On the 'Fuzzification' Group Box the user can verify the inputs and output range by adjusting the position on the Track Bar. This makes the trial and error work become easier to obtain the best performance of the Fuzzy AVR. On the 'Defuzzification' Group Box, the user can freely choose the desired defuzzification method. There are two choices, 'Weighted Average Method' and 'Max Membership Method'.

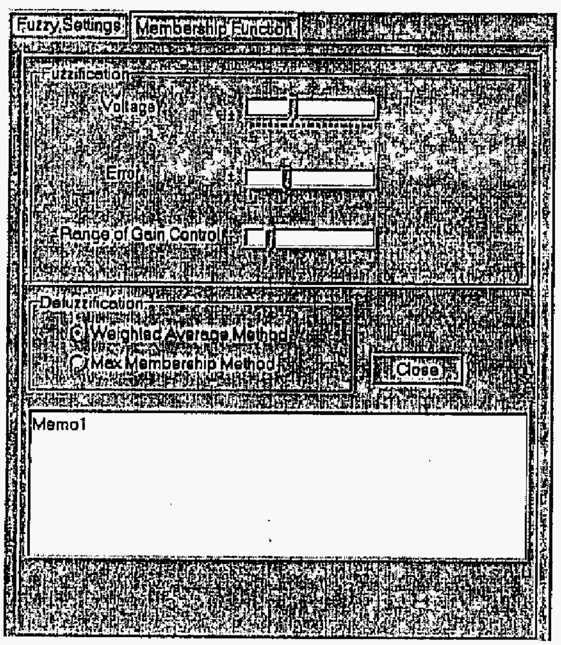



Fig. 5. The Fuzzy Setting Tab Sheet of The Fuzzy AVR

The second tab sheet is the 'Fuzzy Rules' tab sheet. This tab sheet let the user to modify the controller rules during the operation. Normally, rule definition is based on the operator's experience and engineers knowledge. Fig. 6 shows the membership function tab sheet of the Fuzzy AVR.

The users can also change, add or remove the membership functions by selecting desired combination of rules in 'Membership Function Settings' group box and click on the 'Change' button.

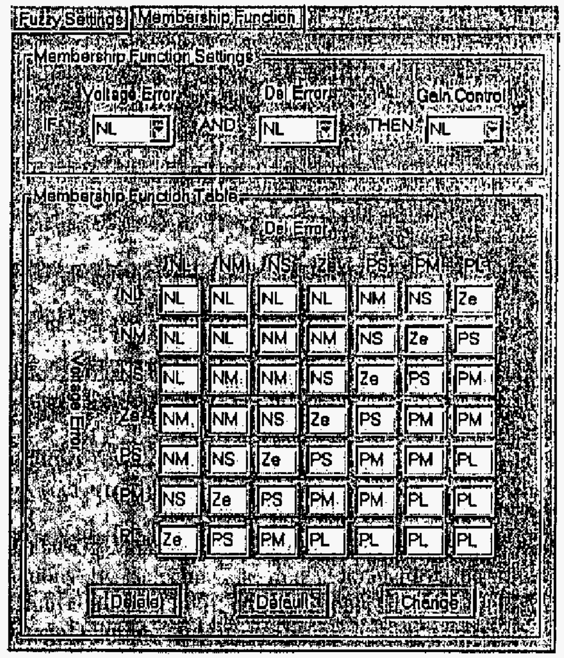



Fig. 6. The Membership Function Tab Sheet of The Fuzzy AVR.

## V. EXPERIMENTAL RESULTS

To obtain the experimental results the controller (PI and Fuzzy Logic) is implemented on an IBM PC and attached to a 5 kVA micro-Alternator. The generator is driven at synchronous speed 1500 rpm by a 8 hp DC motor connected to a fixed 200V dc source. As the generator is loaded the DC motor speed remain constant since a feed-back closed-loop PI controller is used.

Fig. 7, 8, 9, 10 and 11 show the system is tested at 100% load at a power factor 0.6 lag, 0.8 lag, units, 0.8 lead and 0.6 lead respectively. The load is applied at 2 seconds and released at 5 ms later so that the system returned to its steady state.

Initially an open-loop response is recorded and the terminal voltage drop to 0.5 pu then a PI controller is applied and the voltage drop to 0.9 pu. The response shows an improvement to the open-loop response.

Finally is FL controller is introduced and it shows that the response is better as compared to the open-loop system and PI controller. The results show that the Fuzzy AVR damp out the system faster as compared to the open-loop system and PI AVR.

The experiment is repeatedted but with load applied at 2 second, and removed at 4 second later. Similarly Figure 14, 15, 16, 17 and 18 show that FLC AVR damp out the system faster as compared to the open-loop system and PI AVR.

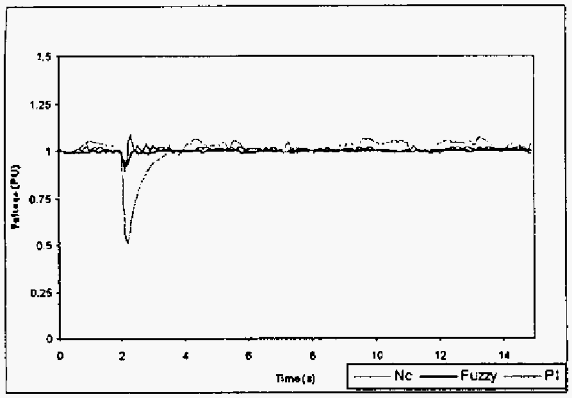



Fig 7. Characteristic output voltage, Load 100%, 5ms, power factor 0.6 lag.

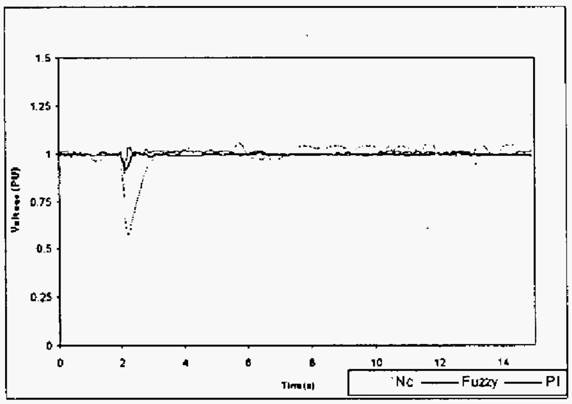



Fig 8. Characteristic output voltage, Load 100%, 5ms, power factor 0.8 lag.

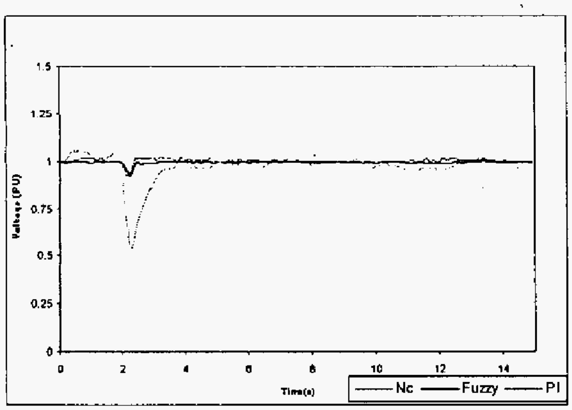



Fig 9. Characteristic output voltage, Load 100%, 5ms, power factor 1.

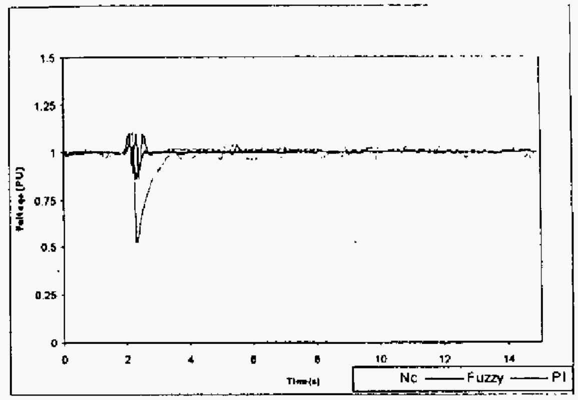



Fig 10. Characteristic output voltage, Load 100%, 5ms, power factor 0.8 lead.

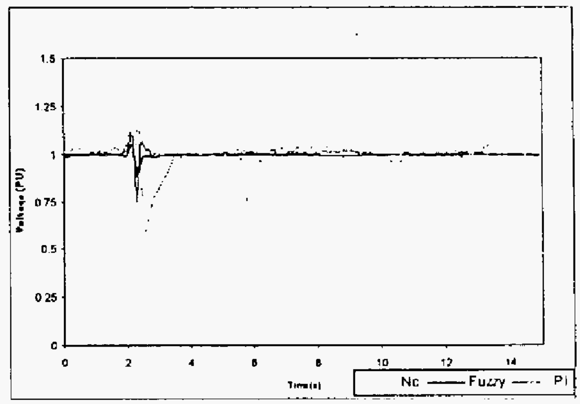



Fig 11. Characteristic output voltage, Load 100%, 5ms, power factor 0.6 lead.

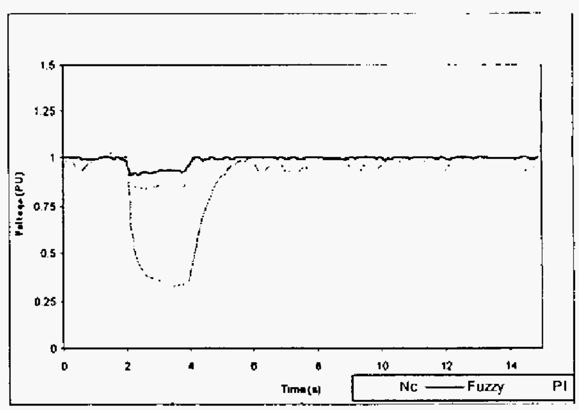



Fig 12. Characteristic output voltage, Load 80%, 2 s, power factor 0.6 lag.

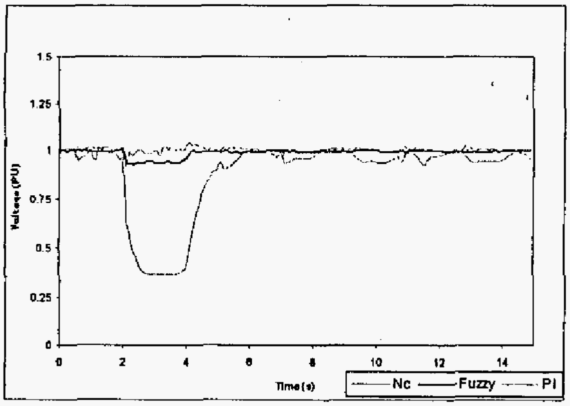



Fig 13. Characteristic output voltage, Load 80%, 2 s, power factor 0.8 lag.

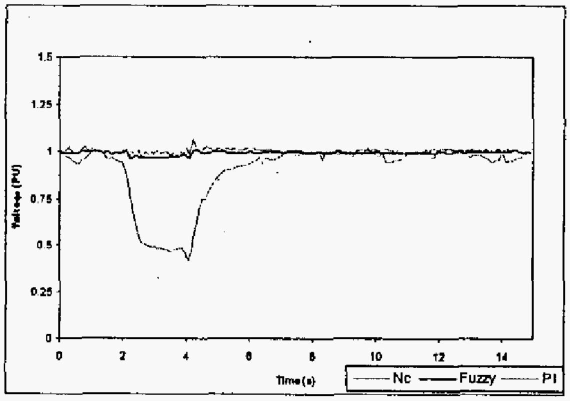



Fig 14. Characteristic output voltage, Load 80%, 2 s, power factor 1.

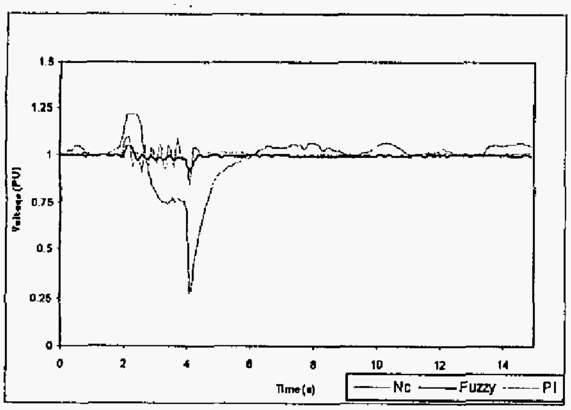



Fig 15. Characteristic output voltage, Load 80%, 2 s, power factor 0.8 lead.

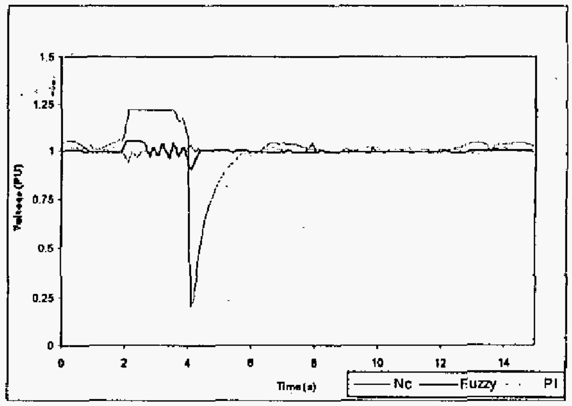



Fig 16. Characteristic output voltage, Load 80%, 2 s, power factor 0.6 lead.

## VI. CONCLUSION

The proposed FLC AVR are compared to the open lood system and PI AVR. Results of these studies have shown that the Fuzzy AVR have successfully damps the oscillation mode on the micro-alternator.

## VII. REFERENCES


[1] A.R Hasan, T. S. Martis and A. H. M. Sadrul Ula, "Design and Implementation of a fuzzy controller based Automatic Voltage Regulator for a synchronous generator" *IEEE Transaction on Energy Conversion*, vol 9, No 3, Sept. 1994.

[2] Frank Engo, *Program Delphi 3*, Copyright by Macmillan Computer Publishing, USA, 1997.

[3] Anderson, Fouad, *Power System Control and Stability* U.S.A. : Iowa State University Press, 1997.

[4] Gupta and D. P. Son, *Electrical Machine Dynamic*, London Macmillan, 1980.

[5] G. Anderson, "Fundamentals of Fuzzy Logic: Parts 1,2,3". *SENSORS*, March-May, 1993.

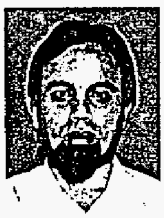
[6] Marzuki Khalid (1999). *Sensing Technology and Machine Language*, Universiti Teknologi Malaysia, 1999.

[7] A.E. Guile, *Electrical Power Systems*" vol.2. England: University of Leeds, 1997

## VIII. BIOGRAPHIES

**Saiful Jamaan** was born in Padang, Indonesia on October 31, 1964. He received the B.S degree in Department of Electrical Engineering from Bung Hatta University, Padang, Indonesia in 1992 and receiving his M.S. degree from the Department of Power Engineering, Faculty of Electrical Engineering, Universiti Teknologi Malaysia in 2000. He is currently a Ph.D student at Faculty of Electrical Engineering, Universiti Teknologi Malaysia. His research interests include Digital Control, On Line Monitoring, Labeling and Standardization, Demand side Management, and Design of Power System Stabilizer Using Neuro-Fuzzy Base on PC.

**Md Shah Majid** received his B Sc dengee in Electrical and Electronic Engineering from University of Strathclyde in 1980 and M Sc in Power System Analisis from UMIST, United Kingdom in 1985. Currently he is an Associate Professor in the Faculty of Electrical Engineering, Universiti Teknologi Malaysia. His research interest include energy efficiency, demand side management and its environmental impact and application of control schemes to power system.



**Mohd. Wazir Mustafa** received his B.Eng degree (1988), M.Sc (1992) and PhD (1997) from University of Strathclyde. His research interests include power system stability, Flexible AC Transmission System, wireless power and power system distribution & automation. He is currently an Associate Professor of Faculty of Electrical Engineering, Universiti Teknologi Malaysia. Dr. Mustafa is also a member of Institution of Engineers, Malaysia (IEM) and a Member of IEEE.

**Hasimah Abdul Rahman** received her B Sc in Electrical and Electronic Engineering from University of Aberdeen, United Kingdom in 1988. She obtained her M Sc in Energy Studies from University of Wales College, Cardiff in 1995. Presently she is a lecturer in the Faculty of Electrical Engineering, Universiti Teknologi Malaysia with particular interest in alternative energy technology, energy efficiency and demand side management.